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ENVIRONMENTAL NOISE POLLUTION CAUSED BY JET AIRCRAFT TRAFFIC

G. Zimmermann

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G. Zimmermann

ABSTRACT: A survey is presented of commerical jet aircraft noise problems, and possible ways to minimize these in the vicinity of airports. Quantization measures of noise, such as perceived noise level are discussed and the Q-formula developed for Germany is given. Possible means of engine noise reduction, such as bypasses, are shown. The noise situation in the vicinity of an airport is investigated noting noise abatement profiles to reduce annoyance. A recent German law to limit aircraft noise is mentioned.

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Anti-Aircraft Noise Society of Mainz

Boork, Mainz, Zeppelinstrasse 91

From the "Allegemeine Zeitung" --

1. Introduction /1**

Recently, since an individual living near Munich's Riem Airport protested against the loud aircraft traffic by trying to shoot down the planes with dumplings, it has been clear that aircraft noise is not an insignificant problem. As a matter of fact, the problem has long been a source of annoyance to those involved, those living near airports, airport operators, aircraft companies and the aircraft industry. After long discussions, the German lawmakers have also reacted by the passage of the law for protection against aircraft noise [1].

The noise from aircraft first became a problem due to the sensitivity of persons to noise. In the chain which is composed of a noise source, transmission path and receiver, the receiver (the individual disturbed by the aircraft noise) is the measure of the problem. Hence, we shall discuss in the following measures for determining the disturbing effect of noise, especially aircraft noise.

*See N72-19031 for original German text.
**Numbers in margins indicate pagination in original text.

Following a brief survey of the developmental tendencies in aircraft construction and in air traffic, the noise situation in the vicinity of an airport will be discussed. Finally, we will go into more detail regarding the aircraft noise law.

In the absence of a regular supersonic air traffic, commercial aircraft do not produce any noise pollution, so that only the noise situation in the vicinity of airports will be discussed. /2

2. Subjective Perception of Noise

A rational solution for the aircraft noise problem assumes quantitative measures for the disturbing effect of noises.

First of all, a distinction must be made between measures for loudness and noisiness of a noise. Measures have been established for both in hearing comparison tests with the aid of appropriate groups of experimental individuals. For a more simple treatment, methods of calculation have been developed in which this measure can be traced back to the instantaneous noise spectrum, so that direct measurement methods have been developed. The details will be found in the appropriate national and international standards [2-8].

With particular emphasis on aircraft noise, the aircraft noise conference held in November 1969 by the International Civil Aviation Organization (ICAO) decided that a measure for the instantaneous noisiness of an aircraft sound should be established on an international level and consist of a perceived noise level (PNL) measured in PNdB. The PNL is calculated from the instantaneous Terz spectrum of the noise involved. If there are pronounced peaks in the spectrum, corresponding to prominent pure tones in the noise, they must be taken into account in correcting the tone. This gives the tone-corrected perceived noise level (PNLT) in PNdB.

A doubling of the noise impression corresponds to an increase of approximately 10 PNdB.

Finally, the time duration of a noise plays an important role in the disturbing effect which it produces. This is expressed in the effective perceived noise level (EPNL) measured in EPNdB. This is obtained from a PNLT-time-history of the noise by integration.

A Boeing 707 on takeoff generates approximately 115 EPNdB when it flies 300 meters over the ground.

An approximate PNL is obtained when certain additional corrections are made/3 to the sound level A (SLA) in dB(A) or to sound level D (SLD) in dB(D), which may differ for different classes of aircraft. Similarly, an approximate PNLT is obtained by supplementary corrections from the SLA, SLD or PNL.

An approximate EPNL is obtained from the chronologically maximum PNLT of a noise by addition of a constant correction factor. As the duration, that period of time is used in which the instantaneous PNLT deviates from its maximum value by less than 10 units (10 dB down time).

The exact or approximate determination of PNL and EPNL is given in the report of the ICAO Aircraft Noise Conference [9] in Chapter 1, Appendix A and Chapter 5, Appendix A.

The EPNL is valid for individual noises with durations on the order of minutes. The noise situation at a point in the vicinity of a commerical airport, on the other hand, consists of the consequences of such noises. In order to evaluate the disturbing effect of such consequences of noise, the ICAO Noise Conference has proposed a unit known as the equivalent continuous perceived noise level (ECPNL)

$$ECPNL = 10 \lg_{10}\left\{\frac{T_0}{T}\sum_i 10^{\frac{EPNL_i}{10}}\right\} \tag{1}$$

Here the subscript i represent represent the individual noises in the aftereffects of the noise. $EPNL_i$ is therefore the EPNL of the i-th noise. T is the relative time interval within which the noise consequences appear, say the 24 hours of a day, and T_0=10 s is a time constant. In order to take into account the difference in disturbing effects of a noise during day or night, the 24-hour day can be divided into a day and a night, or into day, evening and night periods, with the noises in these periods being evaluated differently. This

leads to a different definition of the WECPL (Weighted Equivalent Continuous Perceived Noise Level) and to the WECPNL (2) for the 2-period day or to the WCPNL (3) for the 3-period day. More detail will be found in [9], in Chapter 1, /4
Appendix C and Chapter 2, Appendix A.

In Germany, the $\overline{Q}$ formula (See [10, 11, 12]) has been developed, according to which the following definition is provided as a measure of the disturbing effect of a series of individual noises that occur in a relative time period T, each characterized by the maximum level L_i and duration T_i:

$$\overline{Q} = k \lg_{10} \left\{ \sum_i \frac{\tau_i}{T} 10^{\frac{L_i}{k}} \right\} \qquad (2)$$

Here k is an equivalence parameter that must be determined experimentally, with values between 10 and 15. In the specific form, the $\overline{Q}$ formula has found applications in the German aircraft noise law [1], which will be described in more detail later on. The value of k has been set at 13.3. Sound level A has been used as a level L. The duration T is defined as "10 dB-down-time". The $\overline{Q}$ value is calculated twice, on one occasion using the 16 hours between 0600 and 2200 as a relative time C and on another occasion using the 24 hour day, divided into a day period (0600-2200) and a night period (2200-0600). In the second case, each night flight is counted five times. The larger of the 2 values is $\overline{Q}$ value as defined by the law. This method takes into account the greater sensitivity to noise on the part of individuals during the night, without underevaluating situations with low night flight traffic.

The $\overline{Q}$ formula is valid for conventional aircraft noises. There is an expanded proposal which takes into account supersonic booms [13].

In other countries, similar indices are used, so that in the USA there is the NEF (Noise Exposure Forecast). International uniformity is not absolutely necessary for national use, but it is desireable for a more convenient exchange of information concerning aircraft noise. There is a proposal for standardization which has been set forth by the International Organization for Standardization [14]. Any of these aircraft noise indices may be based upon sociological studies which have revealed a significant correlation of the level of the index

with the behavior of the portion of the population which is involved. In /5
Germany, such an investigation in the noise research program of the German Research Society is currently at the stage of evaluation.

3. Noise Source

The source of aircraft noise is the jet engine (see also A. Scholz: The Environmental Effects of Aircraft Turbine Engines, this publication, pg. ...).

The first generation of jet aircraft was driven by single-stage engines. In this type of engine, all of the air that enters passes through the combustion chambers and is expelled as a stream of exhaust gas. A compressor is mounted ahead of the combustion chambers, and is driven by a turbine located in the exhaust gas stream. In these engines the noise is produced almost exclusively by turbulent mixing in the exhaust stream. This noise is broadband, with a maximum in the range of a few hundred Hz and is highly dependent upon speed and thrust. Special nozzle shapes and ejectors have been used to damp this noise, allowing a more rapid mixing of the exhaust gas with the surrounding air.

Later, the construction of 2-stage engines began (see Figure 1). In these engines, a blower is mounted ahead of the compressor, which accelerates additional air (secondary air) and drives it around the engine proper, allowing it to mix with the exhaust gas stream (primary air). The ratio of the secondary to the primary air is called the bypass ratio. The trend of development is now favoring increasing bypass ratios. Due to the reduced velocity of the stream, the noise of the stream is less in a 2-stage engine. On the other hand, /6
the noise of the blower is louder. It is caused by turbulent flow around the guide and rotor blades, interaction of the rotor blade flow with the flow from the inlet guide blades, interaction of the flow patterns of the individual rotor blades and finally by weak shock waves at the outer ends of the rotor blades, if the latter move at supersonic velocity (especially in large blowers). The noise of the blower therefore contains, in addition to a broadband component in the frequency range around 4-6 kHz, discrete individual tones whose frequencies are governed by the rpm and number of blades in the blower.

Noise-reducing measures consist primarily in a suitable choice of shape, size, and relative position of rotor and stator blades as well as in the covering of the air passageways with noise absorbing material.

For several years now, especially in the United States, research programs have been under way in which the mechanism of noise production in the engine, measures for damping it, and its economic consequences in addition to the subjective reaction of human beings to aircraft noise have been studied.

TABLE 1

Intake	Takeoff	10
	Landing	*15
Primary Flow	Takeoff	25
	Landing	15
Secondary Flow	Takeoff	*15
	Landing	*15
		in PNdB

Expected Noise Reduction with A "Quiet Engine" as Compared to the JT3D Engine.

Thus, under the direction of the National Aeronautics and Space Administration (NASA), the program "Quiet Engine" has been underway since 1966. This program is intended to pass through a series of intermediate stages which will eventually lead to the manufacture of a demonstration engine to be delivered by General Electric to NASA in 1972. The goals are listed in Table 1 as a drop in the level of PNdB with respect to the widely used JT3D engine made by Pratt and Whitney Aircraft Company. The "takeoff" values are valid for a point /7 below the takeoff path at a distance of 4.8 km from the end of the runway and the "landing" values for a point within a 3° landing path at a distance of 1.6 km from the end. It is hoped that the values marked with an asterisk can be improved by a further 10 PNdB by means of acoustically absorbing coverings.

Also with the support of NASA, the firms of McDonnell/Douglas and Boeing have investigated the possibilities of noise damping by means of acoustically absorbing coverings of the intake and especially the secondary flow channels. Improvements on the order of 10 EPNdB (McDonnell/Douglas DC-8, short exhaust channel for the secondary flow) and 15 EPNdB (Boeing 707, longer outlet channel for the secondary air) have been achieved in flight tests. If (as we are to assume) this reduction of noise was achieved by dropping the level while the duration of the noise remained equal, this amounts to at least a halving of the noise impression.

The development of new engines is strongly influenced by noise certificates for new types of aircraft as has been the practice in the United States since November 1969 and is being discussed by the member states of the ICAO at the present time (see [15] and [9], Chapter 3). This means that newly certified aircraft types at certain measurement points under prescribed flying conditions must not exceed noise limits which are a function of the takeoff weight. These data for both the U.S. noise specifications and for the ICAO proposal can be seen from Table 2 and 3. Measurement point 2 is the location of maximum noise on the parallels to the axis of the runway. The noise limit values depend on the maximum takeoff weight. They are constant for maximum takeoff weights above 272 tons and below 34 tons. Between these 2 values interpolation is carried out according to the logarithm of the law of the weight. Table 4 shows a comparison of the actual and desired values for several types of aircraft. The desired values for the Boeing 747 are such that the value for takeoff measurement point 3 was measured without reduction of thrust. With reduction of thrust, it would have been less. According to the latest reports, it has been possible by means of modifications to the engine intake to reduce the landing noise by 4-5 EPNdB and therefore to come close to the desired value. According to an agreement between the Boeing Company and the Federal Aviation Administration (FAA), all aircraft of the Boeing 747 type that are built after 1 December 1971 will satisfy the requirements of the U.S. noise law. This appears possible.

TABLE 4

Aircraft		Measurement Point		
		Landing 1	Take-off 2	Take-off 3
DC9-30	Desired	103	103	95
	Actual	108	103	102
B 707 DC-8	Desired	106	106	104
	Actual	117	106	114
B 747	Desired	108	108	108
	Actual	113	102	115
		in EPNdB		

Comparison of Actual and Desired Values
According to the United States Noise law

The world-wide commerical aircraft fleet of today numbers about 4,000 units, most of them jet-powered. Long-range aircraft of the Boeing 707/DC8 type and medium and short-range aircraft of the Boeing 727, 737 and DC9 types make up about 1/3 and hence the most important fraction of this number.

A doubling of the world aircraft fleet to about 8,000 units must be expected by the beginning of the 1980s. The current models of aircraft of the types described above, with the exception of so-called stretch versions, will stop being produced by the middle of the 1970s. Then the jumbo jets will take over the major role in air travel. Their introduction has already begun with the Boeing 747 and will continue with introduction of the DC10 and the L-10-11. /9
We can expect that these aircraft will carry the majority of air travelers until at least 1990. The fate of supersonic aircraft is unclear at the present time. Predictions about V/STOL transport aircraft are equally useless.

The jumbo jets will satisfy the requirements of the U.S. noise law. It is to be hoped therefore that despite increasing traffic the current noise situation will remain constant in the vicinity of the large commerical airports.

4. The Noise Situation in the Vicinity of Commerical Airports

According to the $\overline{Q}$ formula on page 3 the noise effect of aircraft noise= is specified for a fixed spot in the vicinity of a commercial/airport on the basis of the number of overflights or flypasts and the noises they create and the peak levels and durations. This is in turn determined by the number of aircraft movements and their distribution by aircraft types, takeoff and landing costs and landing and takeoff runways.

Typical traffic figures are approximately 100,000 per year, therefore corresponding to 300 per day for an average German commerical airport and 500,000 per year corresponding to about 1,500 per day for one of the large American commercial airports in the year 1970.

As an example of the calculation of noise zones with the aid of the $\overline{Q}$ formula according to the German aircraft noise law, we shall discuss here the case of a fictitious airport for which the ICAO, on the initiation of the ICAO Aircraft Noise Conference, computed for different countries according to the existing national methods (see[9], Chapter 5, Appendix B). The position of the runway and the landing and takeoff paths can be seen in Figure 2, while the takeoff and landing paths to be used are shown in Figure 3. The number of aircraft movements is shown in Table 5. Calculations used only the aircraft of the Boeing 707 type (long-range) and Boeing 727 (medium-range). The noise level /10
produced can be determined from Table 6. The result is shown in the form of Figures 4 and 5. With the aid of a computer program that already exists in Goettingen, $\overline{Q}$ values could be determined from the existing data for specific points or curves of constant given $\overline{Q}$ value could be computed. In this case, the curves $\overline{Q}$ = 62, 67, and 75 were computed. The values $\overline{Q}$ = 67 and 75 are established in the aircraft law [1] as the limiting values. Experience shows, however, that even at $\overline{Q}$=62 one can expect protests from the population.

The computer provides the coordinates of the points on the curve which indicate the area comprised within the areas bounded by the curves as well as a strip with whose aid an electronic indicating device shows the takeoff path and the approach and takeoff paths and prints the calculated $\overline{Q}$ curve. Figures 4 and 5 show the significant part of the results.

In this case, the areas are 120 km^2, 55 km^2 and 15 km^2. These numbers, corresponding to the number of movements, are representative for a large commercial airport. Preliminary calculations for Chicago's O'Hare Airport for 1975 indicate that for the region NEF > 40 (approx. $\overline{Q}$ > 75) one obtains an area of 70 km^2 and the area NEF > 30 (approx. $\overline{Q}$ > 67) an area of 300 km^2. In this area, approximately 1 million persons are affected by aircraft noise.

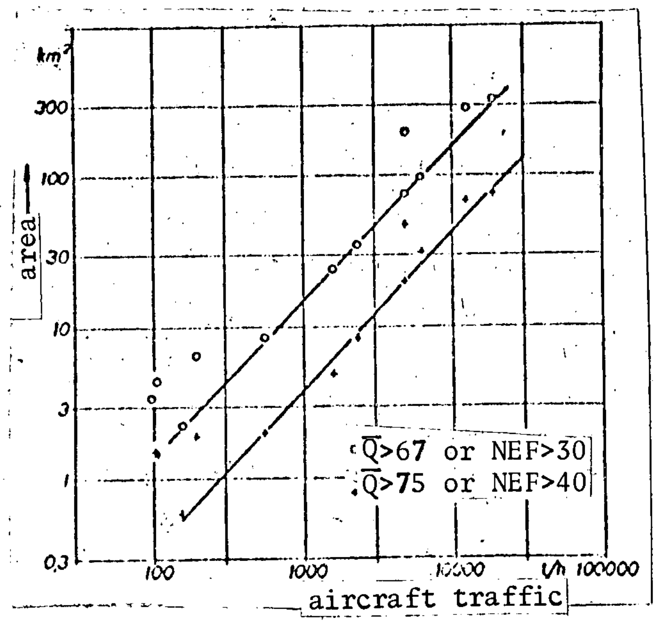

Figure 6

Even more valuable than these figures is a plotting of the area over the traffic in t/h of the maximum takeoff weight for a number of airports in Figure 6 (according to [16]). One can see with some degree of accuracy a proportionality between the area of the areas surrounded by the curves of constant noise and the traffic in t/h of maximum takeoff weight. In particular, for an area /11
$\overline{Q}$ > 75 there is a factor of 0.45 km^2 per 100 tons per hour and for the area

$\overline{Q}>67$ a factor of 1.5 km^2 per 100 tons per hour [16]. Newer studies indicate that the curves in Figure 6 will be displaced downward parallel to each other by the increasing number of jumbo jets which create less noise.

In addition to the possibility of reducing noise in the engines, there is also a possibility of influencing the noise situation in the vicinity of an airport by suitable flight paths on taking off and landing. A familiar example is the reduction of thrust after takeoff, once sufficient altitude has been gained. The reduction of thrust decreases the jet noise and therefore allows quieter flights over a community shortly after takeoff. A disadvantage is that the aircraft remains at lower altitude for a longer period of time. In addition, the method is of little effect in 2-stage engines which have a large percentage of blower noise. A discussion of a number of such noise-reducing flight patterns with their advantages and disadvantages is given in [9], Chapter 4.

5. The German Law to Protect Against Aircraft Noise

Following long discussion, the German law for protection against aircraft noise went into effect on 30 March 1971.

This law establishes noise protection areas around commerical airports and military airports using jet aircraft. As the area to be protected against noise, the law defines the region outside the airport in which $\overline{Q} > 67$ dB(A) with tthe $\overline{Q}$ formula according to equation (2) with the specifications given. The noise protection area is divided into protection zone 1 ($\overline{Q}>75$ dB(A)) and protection zone 2. For the calculation, the 6 months of each year with the heaviest traffic are selected as the reference period T, proceeding on the basis of the predicted traffic to be expected from anticipated expansion of the airport. The establishment of the noise protection area is to be checked at /12
intervals of 5 years and revised if important changes in noise pollution have resulted. One such important change is an increase in the $\overline{Q}$ value at the outer limit of the noise protection area by 4 dB(A). This change would take place for example with a rise in traffic by a factor of 2.

Aside from certain transitional and exceptional provisions, the law provides a ban on construction especially noise sensitive installations like hospitals and schools throughout the entire noise protection area and for residences in protection zone 1. For construction that takes place by special permission as well as houses that are built in protection zone 2, certain noise protection measures are prescribed.

The property owner can demand compensation in the form of money from the aircraft administration for any loss of value of property caused by such construction bans as well as for previously completed investments. In the case of any noise protection measures that are necessary in protection zone 1, the owner of a piece of property or a residence can demand compensation of expenses from the aircraft operator, beginning at the rate of 100 DM per square meter of living space.

One point that could be raised against the noise protection law is that the protective zones are too small. Thus, experience has already shown that $\overline{Q}=62$ will raise protests from the population. Calculation of the zones is supposed to be based on the maximum capacity of the airport, in order to avoid later revisions in the law. Even at small airports the traffic can vary considerably from day to day or with the seasons, so that the zones which are based here on an average traffic are too small when they are measured at peak levels.

If an aircraft noise law had been passed 10 or 15 years ago, which would have required drastic separation of airports and individuals affected by aircraft noise, aircraft noise problems would have been helped considerably. In /13
the meantime, development of communities in the vicinity of airports has eliminated much of the possibility of putting this into effect. In future, however, the separation of air traffic and noise-sensitive populations will remain one of the most important measures to guard against aircraft noise.

Before the law is put into effect, considerable standardization of the methods of calculation in specific cases will be necessary.

6. Conclusions

The discussion of the aircraft noise problem has been limited almost exclusively to the vicinity of airports, since in the current aircraft operation situation the noise problem is particulary acute there. This situation will change in the future because of the increasing number of small aircraft and possibly the introduction of supersonic travel.

Traffic involving sport and small private planes will be bound to increase on weekends over residential and vacation areas and will have a particularly disturbing effect. This development has just begun and can still be regulated.

The traffic of supersonic aircraft has been an ordinary thing in the military for a long time. In the case of civilian air travel, it will commence with much larger and heavier airplanes (compared with military aircraft), possibly in the course of this decade. Supersonic aircraft are driven by one-stage or two-stage engines with very powerful thrust and a low bypass ratio, and therefore develop considerable noise on takeoff and landing. When cruising, they produce the unavoidable supersonic boom whose intensity is dependent less upon speed than on weight, displacement effect, and flight altitude and is therefore much more serious for the proposed supersonic aircraft than for the existing military supersonic planes. The possibility of a considerable /14
problem with sonic booms with respect to the population has led in the United States to the passing of a regulation (notice of proposed rulemaking) by the Federal Aviation Administration which essentially forbids civilian supersonic air traffic above the territory of the U.S.A. Similar rules are already in effect in other countries, for example Switzerland. Statements from the Federal Ministry of Transportation indicate that a ban on civilian supersonic flight is planned for the Federal Republic of Germany as well.

Thus far, nothing has been said about the direct or indirect damage to health caused by aircraft noise. The health-damaging effect of noise has been studied in a number of papers (see for example [17]). Its relevance for aircraft noise is being checked (among others) in the above mentioned aircraft noise project of the German Research Society. Whatever the result may be, the population is becoming aware to an increasing degree of its right to quiet and privacy and is trying to assert its right. Thus, in the United States, as in many civilized areas, an increasing number of protests and activities against aircraft noise are making themselves evident, although the noise situation has improved somewhat with stagnating air travel. This might be decried as an irrational attitude hostile to technical progress. For this reason, the pressure to do away with it is not as great as it might be. This will become increasingly simpler the earlier it happens.

The author would like to take this opportunity to thank Professor Dr. E.-A. Muller and Dr. K. Matschat for their kind assistance in preparing the manuscript. /15

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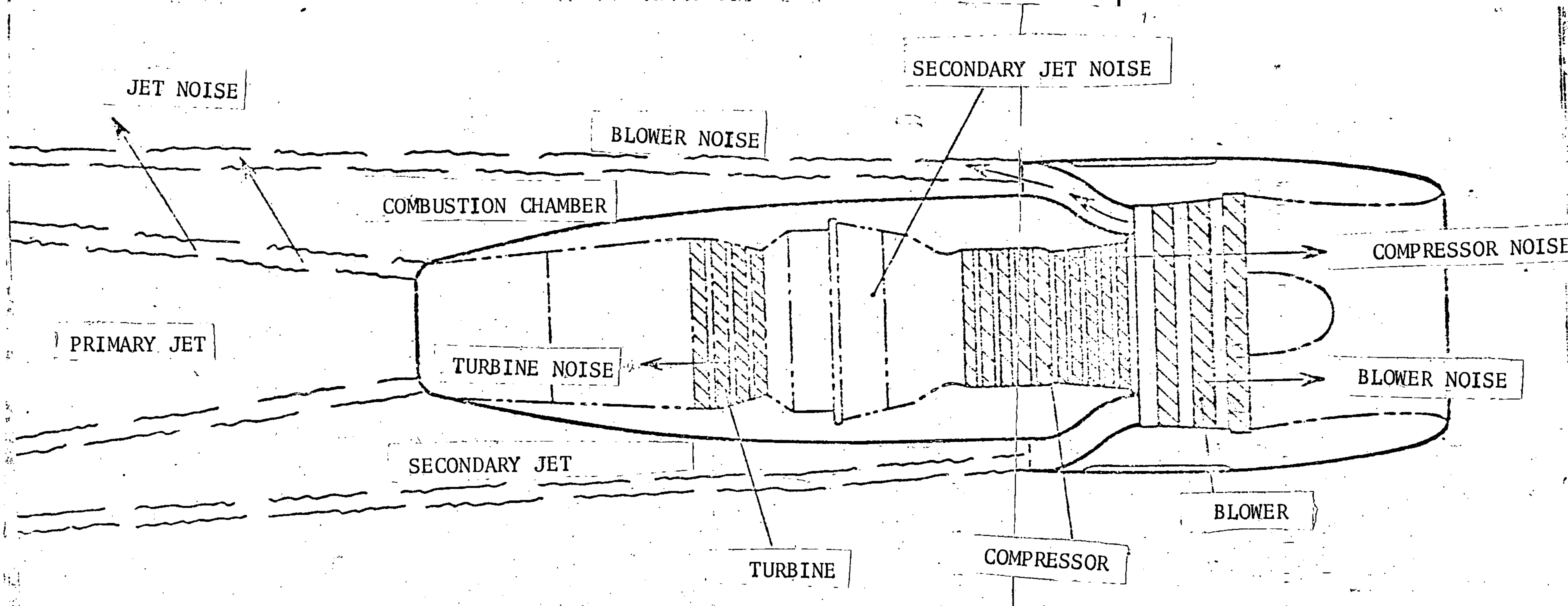


FIGURE 1: TYPICAL TURBOJET ENGINE WITH ITS NOISE SOURCES

FOLDOUT FRAME /

FOLDOUT FRAME 2

SCALE: 1 cm = 1 km

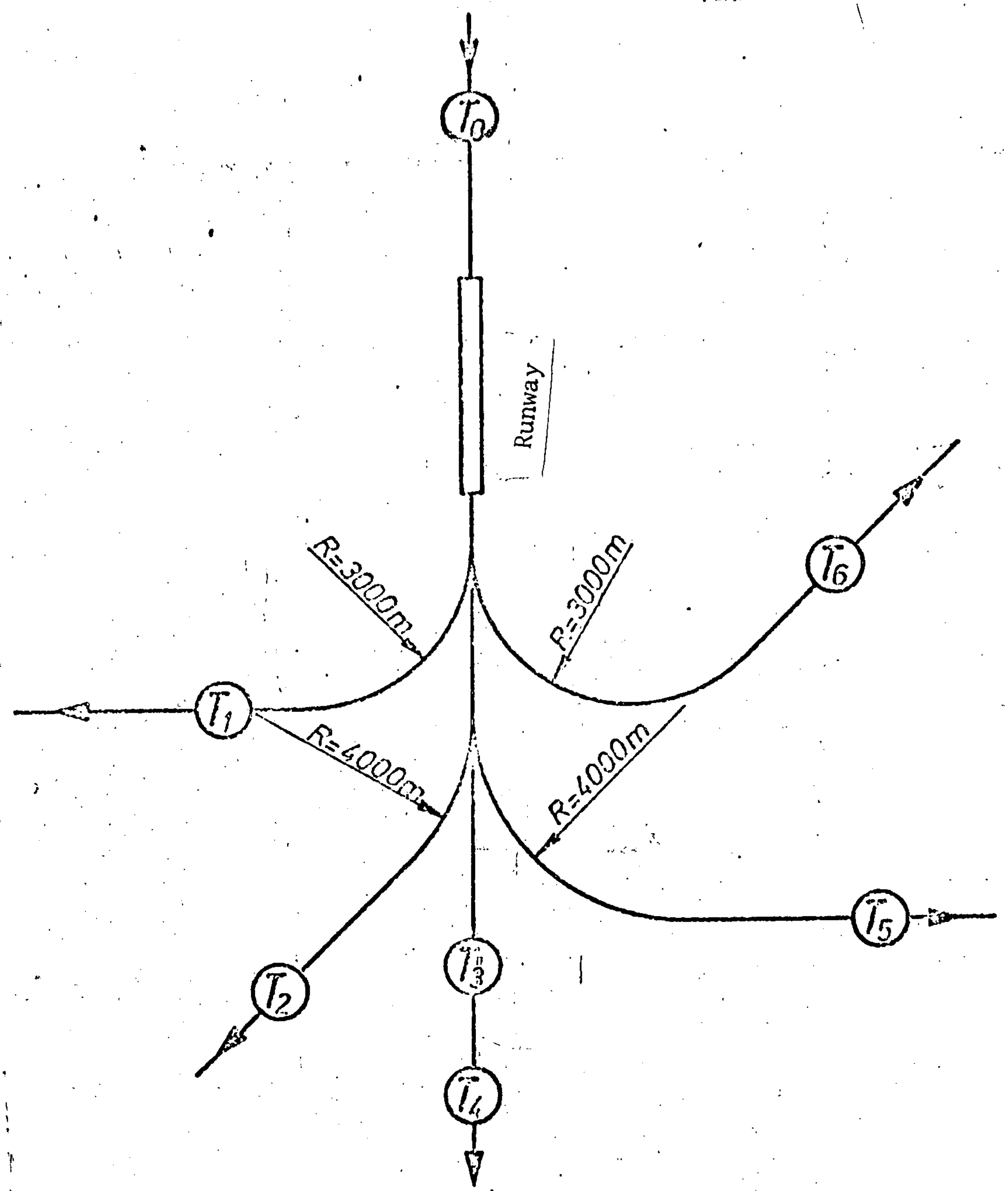


FIGURE 2: ICAO - EXAMPLE. POSITIONS OF TAKEOFF AND LANDING PATHS

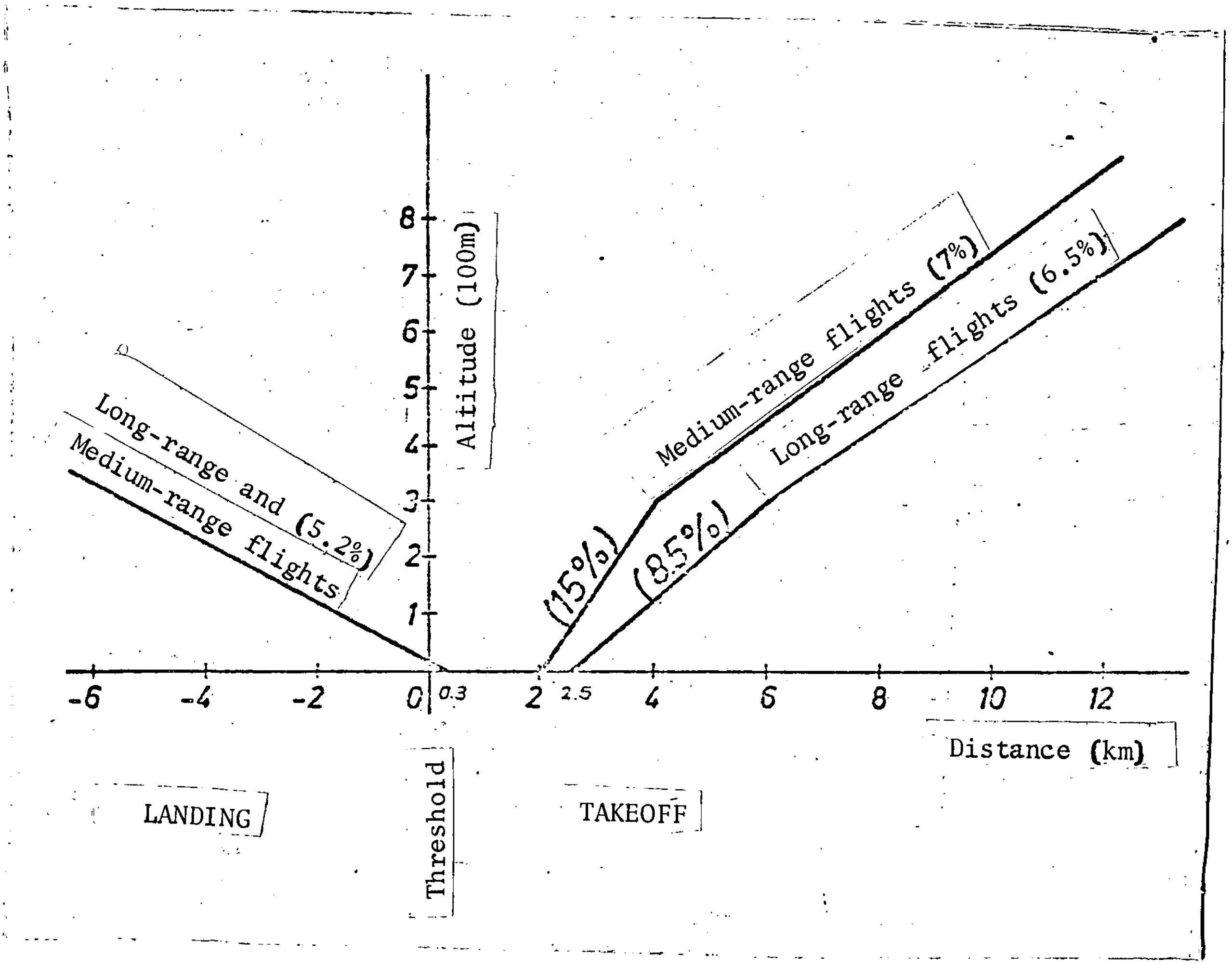


FIGURE 3: ICAO - EXAMPLE. LANDING AND TAKEOFF PROFILES.

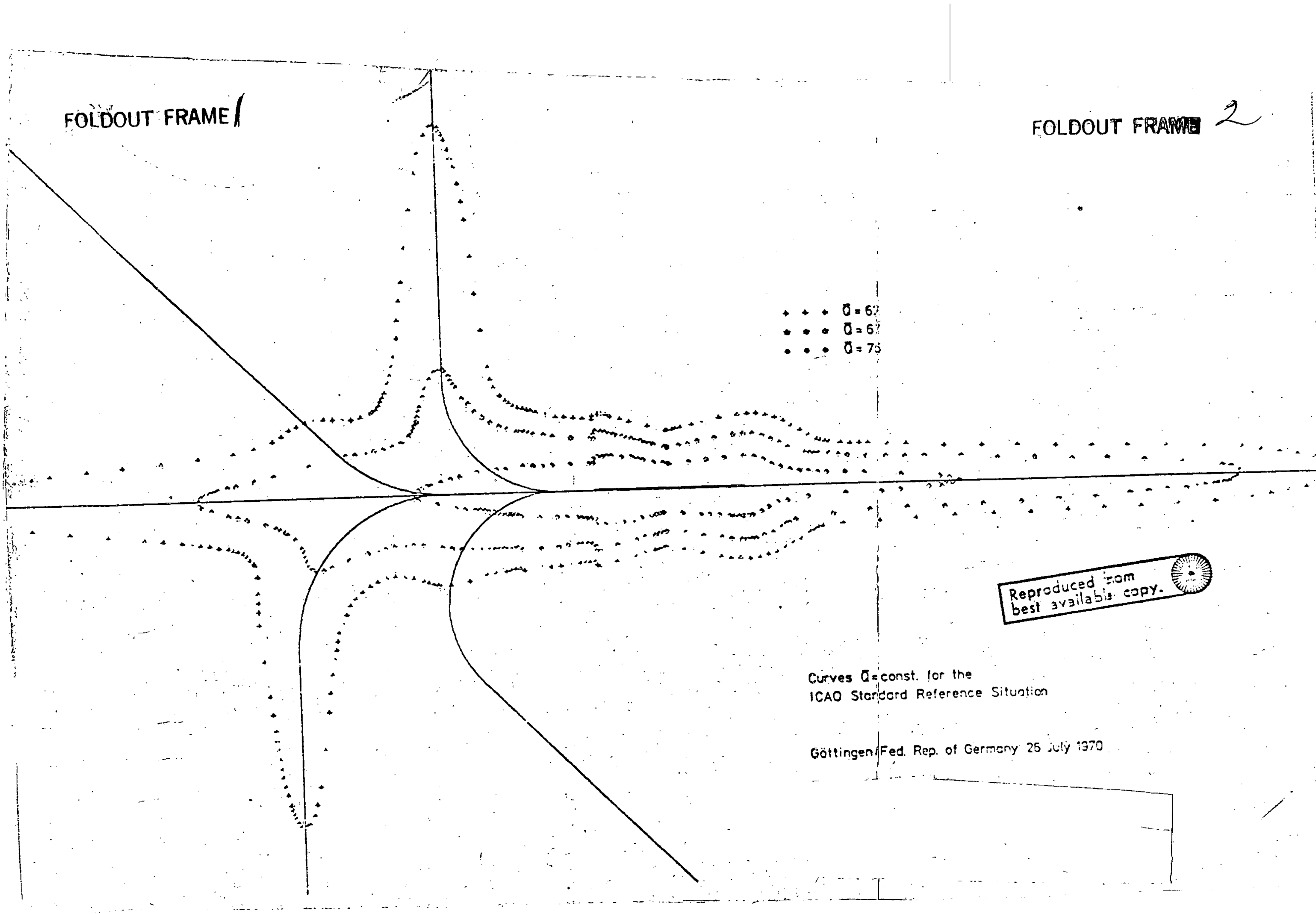


FIGURE 4: $\overline{Q}$ CURVES FOR THE ICAO-EXAMPLE

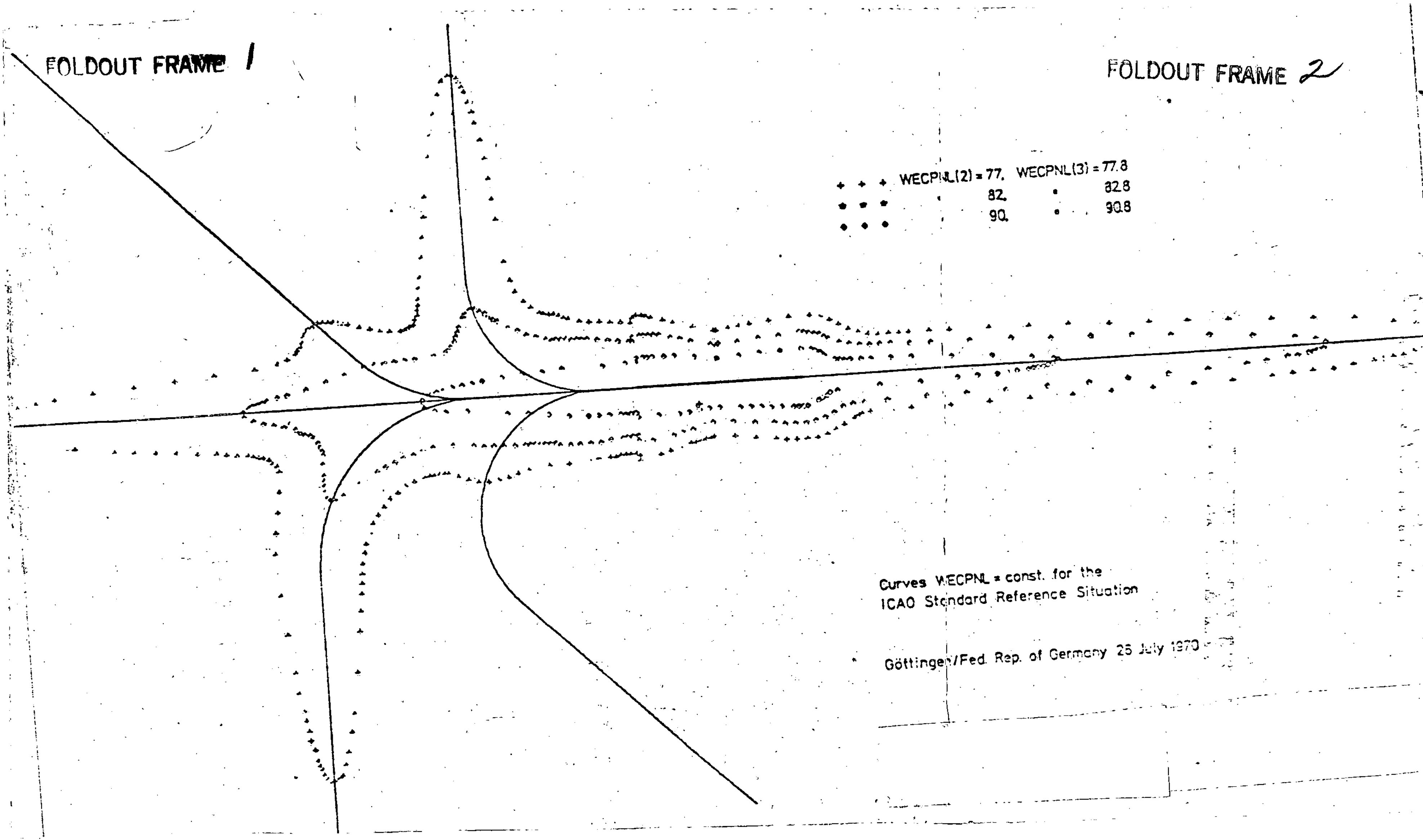
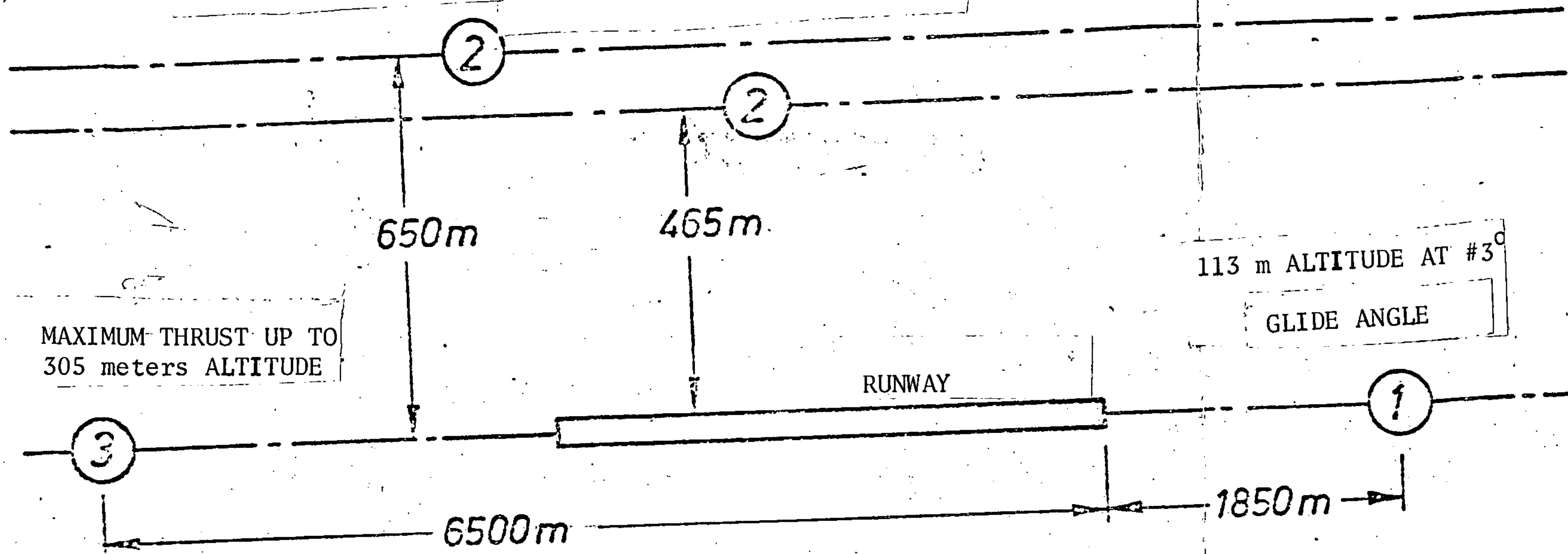


FIGURE 5: WECPNL CURVES FOR THE ICAO-EXAMPLE

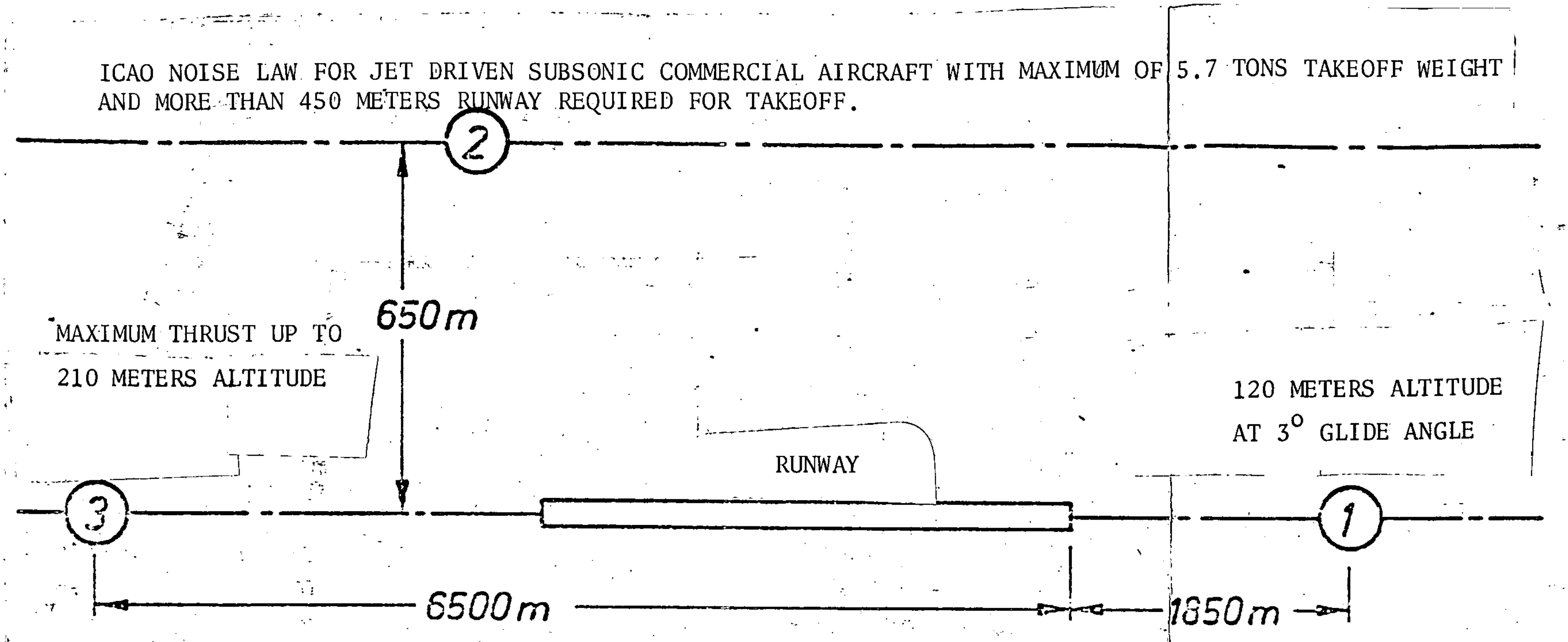
U.S. NOISE LAW OF 17 November 1969 FOR SUBSONIC COMMERCIAL AIRCRAFT AND SUBSONIC AIRCRAFT WITH JET ENGINES

More Than 3 Jet Engines



WEIGHT	1 u. 2	3
≥ 272 t	108 EPNdB	108 EPNdB
≤ 34 t	102 EPNdB	93 EPNdB
WEIGHT-HALVING	-2 EPNdB	-5 EPNdB

TABLE 2: DATA FOR THE US NOISE LAW



WEIGHT	1 u. 2	3
≥ 272 t	108 EPNdB	108 EPNdB
≤ 34 t	102 EPNdB	93 EPNdB
WEIGHT-HALVING	-2 EPNdB	-5 EPNdB

TABLE 3: DATA FOR ICAO NOISE LAW

FLIGHT PATH ACCORDING TO FIG. 2	TYPE OF AIRCRAFT MOVEMENT		NUMBER OF MOVEMENTS		
			0700-1900 hours	1900-2200 h	2200-0700 h
T_0	LANDING	MEDIUM-RANGE	150	50	30
		LONG-RANGE	75	25	15
T_1	TAKEOFF	MEDIUM-RANGE	75	25	15
T_2		LONG-RANGE	10	3	2
T_3		MEDIUM-RANGE	60	20	12
T_4		LONG-RANGE	25	8	5
T_5		MEDIUM-RANGE	40	14	8
T_6		LONG-RANGE	15	5	3

FOLDOUT FRAME 1

TABLE 5: ICAO - EXAMPLE OF DISTRIBUTION OF POPULATIONS

FOLDOUT FRAME 2

NOISE AT 300 M ALTITUDE	MEDIUM-RANGE- AIRCRAFT PNL (PNdB)	MEDIUM-RANGE- AIRCRAFT EPNL (EPNdB)	LONG-RANGE- AIRCRAFT PNL (PNdB)	LONG-RANGE- AIRCRAFT EPNL (EPNdB)
DIRECTLY BEFORE THRUST REDUCTION ON TAKEOFF	110	110	116	116
DIRECTLY AFTER THRUST REDUCTION ON TAKEOFF	107	107	115	115
LANDING	98	100	105	108

TABLE 6: ICAO - EXAMPLE. ASSUMED NOISE PRODUCTION